

Earth Science Applied to Coal Impoundment Monitoring

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Abstract

This project responds to community concern over coal impoundments—ponds used to hold the remnants of the coal refining process—throughout the Appalachian coal seam. Community concern is two-fold: first, there is concern that the impoundments are potentially leaking hazardous materials into local waterways, and second is the potential that these impoundments have to breakthrough into underground mines, thereby releasing millions of gallons of coal slurry and water into local streams and rivers. Additionally, public policy is analyzed in order to assess areas that can be improved to insure the safety of the populations throughout the region. The Tom's Creek Impoundment located near the town of Coeburn in Wise County, Virginia is the focus of the final visualization that is created. The three dimensional visual addresses the community's concerns by illustrating the levels of iron and manganese in Tom's Creek—the waterway that flows adjacent to the creek—upstream and downstream of the impoundment, and then highlights areas downstream that would be affected if the impoundment were to break. The result is that the level of iron downstream of the impoundment is generally higher than the level upstream, indicating a potential leakage into the water. Additionally, towns downstream of the impoundment have been identified that could be affected if the impoundment broke. Finally, with regards to public policy, it is identified that there is a lack of federal regulations regarding the underground mines beneath the impoundments; to prevent further impoundment breakthroughs, this is an area that needs improvement. The final product, therefore, is geared towards aiding people and decision makers in the local community to make more informed decisions regarding the dangers posed by coal impoundments. Furthermore, this pilot product is extendable to any impoundment throughout the region, and can also have real time monitoring applications as a Decision Support System for the community as well as the coal company.

1. Introduction

There are approximately 600 coal impoundments located throughout the Appalachian coal seam, which stretches through six-states: Pennsylvania, Ohio, West Virginia, Virginia, Tennessee, and Kentucky (“Coal Waste Dams and Impoundments”). Figure 1 plots the location of these impoundments.

Coal impoundments are ponds or abandoned surface or underground mines converted to hold coal slurry (also known as coal sludge), which consists of the remnants from the coal refining process. There is concern among communities in the region that the coal impoundments could potentially be leaking hazardous materials into local waterways, posing a serious environmental threat to the surrounding ecosystem and a danger

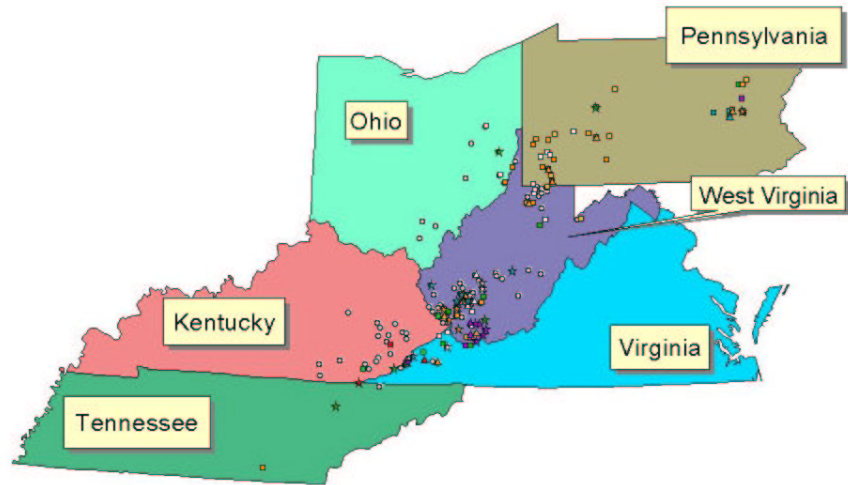


FIGURE 1: Coal Impoundments (“Coal Waste Dams and Impoundments”)

to the health of the populace. Additionally, there have been multiple impoundment failures in recent years, where underground mines beneath the coal impoundment ponds have collapsed, and the sludge has spilled out of the mine openings and into surrounding rivers. These spills have caused massive ecological disruption and cost millions of dollars to clean up. The effects on the local populations have also been catastrophic, ranging from the contamination of local drinking water supplies and the killing of aquatic life to the damage of people’s homes and businesses.

Based on requests from state and local governments, this project was undertaken to assess the potential effects of coal impoundments on local communities and to determine what areas downstream could be affected if a coal impoundment were to breakthrough into an underground mine. Additionally, in conjunction with this research, public policy and legislation regarding coal impoundments will be assessed and recommendations will be made for improvement in order to better protect communities in this region. Because of the limited timeframe of this project, a specific site was selected to investigate. The coal impoundment analyzed in this project is the Tom’s Creek Impoundment (also known as Salies Branch Slurry Impoundment), located in Wise County, Virginia, near the town of Coeburn.

Adhering to DEVELOP’s theme of “Community Benefits of Earth Science,” the final product consists of a three dimensional visualization, which will allow students and decision makers to identify hazardous wastes that may be polluting underground and surface water sources, as well as to assess the potential damage caused by an impoundment breakage.

2. Background Information

2.1. Coal Impoundments

One of the largest sources of fuel used domestically, coal plays a major role in the economy of the Appalachian coal seam region. The United States in itself owns about 25.1% of the world's coal reserves and in the year 2000, 51.4% of electric power generated was from coal (National Research Council 17). However, as technology takes over the role of miners and as the purest coal fields are exhausted, the quality and purity of the mined coal has decreased. As a result, the amount of coal waste has increased along with the decreased efficiency of using water in the coal-refining process (Michalek 1).

Coal waste is generally classified in two forms. It consists primarily of coarse refuse, which are large rocks that have been separated from the mined material. The fine refuse is a byproduct of the mechanization of the coal refining process, and consists of a mixture of water and finely crushed coal and rock. This mixture is known as coal sludge or slurry (Michalek 1). In the Appalachian region, most impoundments take advantage of the topography of the land to contain the slurry within a naturally occurring basin. An embankment is often utilized at the mouth of a small valley or watershed to complete the impoundment (National Research Council 51). The embankment is similar in structure to a typical dam used in a river, and is built up using the coarse refuse.

In addition to the basic structure of the impoundment, a system must exist to deal with runoff of excess water as well as to prevent overtopping from occurring. The basin acts as a large-scale settling pond, where the coal fines settle to the bottom, and the water on top is often reused in the preparation plant. Excess water, from natural precipitation for example, is removed via a pumping system or diverted using runoff channels into a series of smaller settling ponds, as is the case with the Tom's Creek Impoundment (National Research Council 67). Eventually, the runoff from the last set of settling ponds is discharged into the local waterway (Burns).

2.2. Coal Impoundments Failures

Because of their possibility of failure, coal impoundments have historically been a threat to local communities. There are several mechanisms by which an impoundment can fail, but the two main areas of focus for this project are on dam failure and breakthrough into underground mines. The most deadly of these disasters occurred in 1972, when a coal refuse dam operated by the Buffalo Mining Company near Saunders, West Virginia failed. It was estimated that 132 million gallons of coal slurry and water spilled into the Buffalo Creek tributary of the Middle Fork, killing 125 people and injuring 1,100. Property damage from the disaster was approximated at fifty million dollars (National Research Council 25). Although associated with heavy rainfall in the days leading up to the dam failure, the investigation concluded that the failure occurred because the impoundment had been constructed with "little or no engineering design" (Michalek 2).

More recently, breakthrough into underground mines has attracted attention in the mining community. The accident that has drawn the most media attention occurred on October 11, 2000, in Martin County, Kentucky. A coal impoundment at Martin County Coal Corporation's preparation plant failed, releasing slurry consisting of an estimated 250 million gallons of coal

slurry and water into local streams. According to the company, the failure was caused by a "sudden and unexpected" collapse of an abandoned underground coal mine next to the impoundment. This resulted in the collapse of the bottom of the slurry pond, allowing its contents to pour into the mine tunnels. The slurry then poured out of two mine entrances, about 2 miles apart, into two different waterways—Wolf Creek and Coldwater Fork. Approximately 75 miles of rivers and streams were polluted with slurry, killing aquatic life along the Tug Fork of the Big Sandy River and some of its tributaries, and forcing towns along the Tug Fork to turn off their drinking water intakes. The spill contained measurable amounts of heavy metals, including arsenic, mercury, lead, copper and chromium. The full extent of the environmental damage is unknown, but estimates of the cleanup costs reach as high as \$60 million. Unlike the Buffalo Creek incident, however, there were no injuries or fatalities as a result of this spill (National Research Council, 30).

2.3. Public Policy

2.3.1. Coal Impoundments

Identifying areas needing legislation passed or altered may decrease adverse affects of impoundments. Therefore, it is important to analyze current legislation and methods of implementation applied to the various dangers of coal impoundments. Numerous government agencies and laws exist that address impoundment safety, especially in response to disasters such as Buffalo Creek.

The Surface Mining and Reclamation Act of 1977 established the Office of Surface Mining under the Office of the Interior. This act states that due to diversity in physical conditions in each region, states with a mining industry should strive to obtain primacy by developing a program that demonstrates the states capability to regulate mining activities. This includes the regulation of impoundments. In states which have obtained this primary regulatory responsibility, the Office of Surface Mining takes an oversight role. Virginia obtained primacy through the establishment of the Department of Mines, Minerals, and Energy. The Office of Surface Mining also promulgated the buffer zone rule of 1981, which stated that no unapproved mining activities may exist within 100 feet of a perennial or intermittent stream. In Virginia, water monitoring is required in streams local to impoundments, as well as inspections quarterly and during critical phases. The Surface Mining and Reclamation Act also requires engineering plans of a coal impoundment to be submitted and cross referenced with the Mine Safety and Health Administration's requirements. In addition, an analysis and investigation of the structure, the land, and the possible effects of the structure prior to the review and approval process is required (National Research Council, 41).

The Federal Mine Safety and Health Act of 1977 assessed the Mine Safety and Health Administration's role in the regulation of impoundments and impoundment breakthroughs. Under the Federal Mine Safety and Health Act, the Mine Safety and Health Administration must approve all plans for impoundments. Part of this applies to new underground mines, as it requires the locations of all mine workings within 500 feet to be identified. A registered professional engineer must also approve all impoundment plans. The review and approval process is through the district manager of the Mine Safety and Health Administration. The Mine Safety and Health Administration requires certified inspections of impoundments, which show

an impoundment's stability and adherence to set standards. This inspection usually fulfills the state's requirements, unless a state requires water-sampling data. This inspection's results must be submitted to the Mine Safety and Health Administration annually in an annual report (National Research Council, 35).

Since the inception of these aforementioned agencies and regulations, there have been no dam failures at coal impoundments ("Coal Waste Dams and Impoundments"). There have, however, been four occasions when coal slurry has broken into an underground mine beneath the impoundment and out the mine openings into the local waterways. Currently, there is no legislation at the federal level regarding mapping of underground mines or setting a minimum distance between the underground mine and the impoundment. At the state level, however, some legislation does exist depending on the state. In Virginia, the state in question, the Virginia Administrative Code requires that the width of the outcrop barrier¹ be at least fifty feet plus one foot for each foot of hydrostatic head² (National Research Council 57). Additionally, before a new impoundment can be constructed, a loop survey must be carried out, which accurately maps all underground mines beneath the impoundment (Baker).

Older impoundments, however, were built before these regulations went into effect, and therefore pose unknown dangers. Inaccurate mapping creates the possibility of an underground mine being closer to the bottom of a pre-existing impoundment than thought, increasing the risk of the underground working collapsing beneath the impoundment. At approximately 9pm on July 24, 2002, nine miners became trapped in the Quecreek Mine near Somerset, Pennsylvania. They broke into a flooded, abandoned underground working adjacent to their active mine. Unfortunately, their maps showed the mine to be 300 feet away. (Puskar). This incident, along with the Martin County spill in 2000, received national news coverage, but neither has yet sparked political action at the national level requiring surveys to detect abandoned underground mine workings.

Mine Safety and Health Administration does, however, have a system in which they rank breakthrough potential of an impoundment into an underground mine. Each impoundment is ranked as having either a low, medium, or high breakthrough potential. This ranking is based on the distance of the impoundment basin to underground working, but does not assess the probability of a failure (National Research Council 32). Additionally, the rankings are further broken down into what potential group or groups would be affected if the impoundment were to break. These include the following: miners on mine property, the general public, property (roads, buildings, utilities, etc.), the environment, and breakthrough would be safely contained within an abandoned mine ("Coal Waste Dams or Impoundments with a Potential to Break into an Underground Mine").

2.3.2. The Environment

In regulation of all refuse disposals, the Clean Air Act, Clean Water Act, Safe Drinking Water Act, Resource Conservation and Recovery Act, Migratory Bird Treaty Act, and Endangered Species Acts federally require impoundments to adhere to standards set therein. The

¹ The outcrop barrier is the distance between the coal outcrop and the underground mine (National Research Council 216)

² Hydraulic head is the pressure against the dam from the weight of the slurry (National Research Council 215).

Environmental Protection Agency, U.S. Army Corps of Engineers, and the U.S. Fish and Wildlife Services implement the appropriate federal standards. Each state additionally may have legislation and agencies addressing similar objectives, which would also apply to impoundments. Federally, specific legislation is found in the Surface Mining and Reclamation Act of 1977, established to protect the local communities and the environment, and in the Federal Mine Safety and Health Act of 1977, established to protect the health and safety of miners (National Research Council, 46).

Of particular concern to this project is legislation dealing with waterways, which would address the possibility of leakage from the impoundment into the local watershed. As aforementioned, coal impoundments are required to adhere to the Clean Water Act and Safe Drinking Water Act (if the receiving waters of the impoundment are a source of drinking water). The Clean Water Act was passed in 1972 to control pollution from point sources, sewage systems, and industrial facilities. Under this act is the National Pollutant Discharge Elimination System, or NPDES. This system is responsible for issuing permits for industrial and municipal wastewater discharges to surface waters, with the purpose of controlling and eventually eliminating pollution from these sources. (“National Pollutant Discharge Elimination System (NPDES)”)

The Safe Drinking Water Act was established to protect underground drinking water sources, as is applicable to impoundments that inject refuse back into underground workings (National Research Council 48). Under this act the Environmental Protection Agency has established National Primary Drinking Water Regulations, or NPDWRs. These are “legally enforceable standards” to “protect public health by limiting the levels of contaminants in drinking water.” Additionally, the EPA has set National Secondary Drinking Water Regulations, which are “non-enforceable guidelines regulating contaminants that may cause cosmetic effects or aesthetic effects” (“Ground Water and Drinking Water”). These regulations, however, only apply where the waterway is a source of public drinking water.

3. Data Collection

3.1. Site Selection

Preliminary research for the project began with conducting the above background research that was necessary before creation of the visualization could occur. From there it became possible to choose a specific site to focus on. There were several criteria involved in making this choice. Since DEVELOP projects are customer demand driven, the first priority was to respond to community concern. A site in McDowell County, West Virginia or Wise County, Virginia, therefore, would have been the best choice, since both of these communities approached DEVELOP with interest in the coal sludge project. Second, the level of possible impact on the communities was assessed, including but not limited to the following: proximity to large populations, nearby waterways, and likelihood of breakage. Finally, it was important that the appropriate data be available for the area in question. This includes remote sensing data, which will be discussed in a later section, as well as water monitoring data for the nearby waterways. It was discovered throughout the data collection process that an active impoundment would also be a necessary parameter, so that monitoring is currently being conducted as required by law. Data collection would be much more difficult for an inactive impoundment.

Originally sites were researched in McDowell County, West Virginia because of their high levels of possible impact. Mine Safety and Health Administration lists nine impoundments in McDowell County, two of which have a high breakthrough potential, and four of which would impact the general public if the impoundment were to break. In Wise County, Virginia, there are 10 impoundments listed, two of which have a high breakthrough potential, but only two of which would impact the general public (“Coal Waste Dams or Impoundments with a Potential to Break into an Underground Mine”).

Initially, data collection also looked promising for West Virginia. Several Geographic Information Systems, better known as GIS, data sets were available from the West Virginia GIS Technical Center (“West Virginia GIS Data Clearinghouse”). However, problems arose when it came to obtaining water monitoring data. Both the United States Geological Survey and the Environmental Protection Agency were researched for water monitoring data on waterways in West Virginia, particularly looking for testing on heavy metals. The only data that was able to be obtained, however, was either outdated or very limited. Further attempts were made to collect this data through phone calls to the various departments within the West Virginia Department of Environmental Protection. After numerous dead ends, it became necessary to choose a site elsewhere since McDowell County could not meet all the criteria. Therefore, the focus of the project turned to the aforementioned impoundment in Wise County, Virginia, which is located nearby Tom’s Creek and close to the town of Coeburn.

The Tom’s Creek Impoundment, formally known as the Salies Branch Slurry Impoundment, is owned by Coastal Coal Company (U.S. Mine Safety and Health Administration 57). It is located approximately two miles northeast of Coeburn, which has a population of approximately two thousand (“United States Census 2000”). Figure 2 illustrates where the town is located. The receiving stream for the impoundment is Tom’s Creek, which flows into the Guest River in the town of Coeburn (“e-Geographical Information System”). According to the Mine Safety and Health Administration, the Toms Creek Impoundment has a moderate likelihood of breakage, and would impact the general public, property, and the environment if it were to break (“Coal Waste Dams or Impoundments with a Potential to Break into an Underground Mine”). On 21 March 2001, the volume of the impoundment was measured to be 2511 acre-feet (U.S. Mine Safety and Health Administration 57).

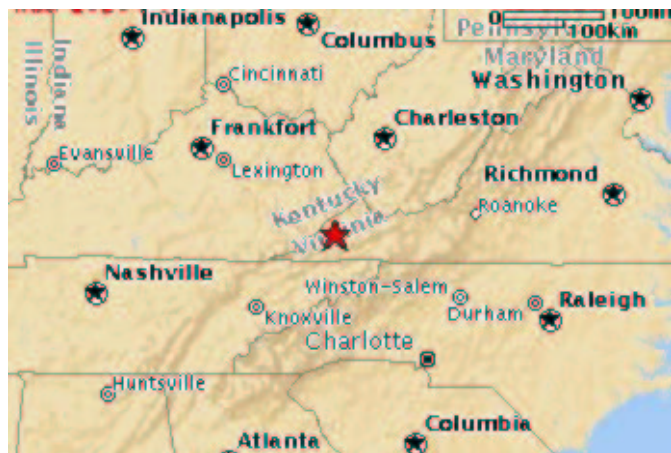


Figure 2: Coeburn, VA (“Mapquest”)

3.2. Water monitoring data

Because the main thrust of this project focuses on the environmental effects of coal impoundments, primarily on the impact on local waterways, obtaining reliable and abundant

water monitoring data was essential to the completion of this work. Because of DEVELOP's focus on remote sensing, initial research was done on the possibility of using remote sensing to detect pollutants in Tom's Creek. After researching spectroscopy, including AVIRIS (Airborne Visible/Infrared Imaging Spectrometer), it was determined that this would not be a viable option. Current available remote sensing technology would not be able to detect the small amounts of metals in the waterways being looked at.

Therefore, the research then turned to obtaining ground data from monitoring stations along Tom's Creek. Initially, USGS and EPA were researched for data on the levels of heavy metals in Tom's Creek. The focus was on heavy metals because they were found in the coal sludge spill in Martin County, and because of their adverse affects on human populations. As in West Virginia, the data available was either outdated or very limited. The focus then turned to contacting Coastal Coal Company as well as the Division of Mined Land Reclamation, which falls under the Virginia Department of Mines, Minerals, and Energy. The DMLR requires Coastal Coal Company to take water quality data on a monthly basis, in their sediment ponds, at several ground water locations, and in Tom's Creek at locations both upstream and downstream of the impoundment (O'Quinn). The upstream monitoring station is approximately 1100 meters from the impoundment and the downstream station is 600 meters away. In all locations, they company is required to test for levels of iron, manganese, pH, and total suspended solids. In addition, they test for the following instream: appearance, color, temperature, acidity, alkalinity, conductivity, total dissolved solids, and sulfates (VA Division of Mined Land Reclamation).

The testing stations in the sediment ponds and groundwater must meet NPDES regulations. Table 1 lists the standards that must be adhered to according to the NPDES (Wiles).

	Daily Maximum Value	Monthly Average Maximum
pH	6 – 8	6 – 8
Iron	6 mg/L	3 mg/L
Manganese	4 mg/L	2 mg/L
Total Suspended Solids	70 mg/L	35 mg/L

TABLE 1: NPDES Regulations

Because Tom's Creek is not a public drinking water source (Wiles), the instream monitoring data is not required to adhere to any standards. To obtain a sense of the scale of the amount of pollution in the water, however, Table 2 lists the EPA's secondary standards for the items that are tested for ("Ground Water & Drinking Water").

Contaminant	Secondary Standard
Iron	0.3 mg/L
Manganese	0.05 mg/L
pH	6.5 – 8.5
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L

TABLE 2: EPA National Secondary Drinking Water Regulations

3.3. Industries affecting local waterways

In researching pollutants in a body of water it is important to understand where the impurities may have come from. The potential impacts of Tom's Creek Impoundment on the local waterways cannot be accurately documented if there are other polluting factors involved. These factors may include point and non-point pollution, sewage overflow, water discharge, toxic releases, hazardous waste, and air emissions from industries and other facilities along the waterway. The EPA's EnviroMapper was used to research industries located in close proximity to Tom's Creek that may also be contributing to the pollution in the water. The information provided by EPA's EnviroMapper shows various types of pollution associated with twelve different industries within the Toms Creek area, including sewage, water discharge, toxic release, hazardous waste, and air emissions ("Enviromapper"). Table 3 lists the various industries nearby Tom's Creek.

Facility Name	Type of Pollution	SIC Code
Sycamore School	Hazardous Waste	Elementary and Secondary Schools
Equitable Production Company/Wise	Air Emissions	Crude Petroleum and Natural Gas
Toms Creek Water Filtration Plant	Water Discharge	Water Supply
Coeburn Battery	Hazardous Waste	N/A
Coastal Coal Company LLC	Air Emissions	Bituminous Coal & Lignite Surface Mining
D & J Feed Incorporated	Air Emissions	Farm Supplies
Wise County Public School/ Coeburn High	Air Emissions	Elementary and Secondary Schools
H & K Contracting, Inc	Air Emissions	Girls', Children's, & Infants Outerwear Not Elsewhere Classified
World of Marble	Air Emissions & Toxic Release	Plastics Plumbing Fixtures
Mitchell Distributing Co	Hazardous Waste	Air & Gas Compressors
Coeburn Norton Wise Regional/Wastewater Treatment Plant	Water Discharge	Sewage Systems
VA. Department of Welfare & Inst	Water Discharge	Sewage Systems

TABLE 3: Industries potentially polluting Tom's Creek

4. Visualization

4.1. Data Layers

To create a meaningful final product, the water monitoring data must be combined with other layers of data. One of the most important types of data required is GIS, or Geographic Information Systems, data. “GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced data” (“Geographic Information Systems”). This makes it possible to combine various data layers, such as water monitoring data, population demographics, and hydrology information, to incorporate all of the factors involved in assessing the risks involved with the coal impoundment and the potential dangers it poses on the populace. DEVELOP uses this layering technique in all of its visuals to respond in order to community demand. Below is described each of the data layers used in creating the final coal impoundment visualization.

4.1.1. County and State Shapefiles (“2000 County and County Equivalent Areas in ArcView Shapefile (.shp) format”)

To begin the visual, shapefiles containing data on the state and county boundaries are necessary to outline the area in question, so that the customer can visualize what part of the country is being looked at. These files contain data, that when brought into ArcView, georeference the borders of the states and counties being examined.

4.1.2. Digital Elevation Model (“Coeburn, VA”)

To make the model three-dimensional, data on elevation of the terrain is required. Digital Elevation Models (DEMs) provide this information in a header file that includes an array in regularly spaced intervals of elevation values that correspond either to a Universal Transverse Mercator (UTM) projection or to a geographic coordinate system, such as longitude and latitude (“US GeoData Digital Elevation Models”). The DEMs used for this project have thirty-meter resolution in Spatial Data Transfer Standard (SDTS) format.

4.1.3. Landsat (“Landsat 7 Full Scenes”)

Satellite imagery can then be layered on top of the DEM so that the three-dimensional model can have a realistic quality. 28.5-meter resolution Landsat 7 imagery from NASA was used to achieve this effect. Landsat uses an eight-band multispectral scanning radiometer capable of providing high-resolution image information of the Earth’s surface. Of the eight bands, combining bands one, two, and three creates images that are closest to natural terrain coloring (“Landsat 7”). Because of the low resolution of these images, they are used in the visual to cover the broad area surrounding Wise County.

4.1.4. Digital Orthophoto Quarter-Quadrangle (“Aerial Photography/Remote Sensing”)

For a closer look at the area surrounding the selected impoundment, five-meter resolution Digital Orthophoto Quarter-Quadrangles (DOQQs) were used. DOQQs—basically, aerial photography—are digitized images combined with georeferencing data for true geographic positioning (“What are Digital Elevation Models...”). The DOQQ dataset used for the visualization came from the University of Virginia, and is of the area immediately surrounding Coeburn, Virginia and the Tom’s Creek Impoundment.

4.1.5. Hydrology (“Free Redistricting Census 2000 TIGER/Line Shapefiles”)

For mapping out the local hydrology, data was obtained from the Topologically Integrated Geographic Encoding and Referencing (TIGER) system of the U.S. Census Bureau. This is a digital database for geographic and statistical information, containing information such as roads, rivers, lakes, and political boundaries. The database contains information on these features in addition to their latitude and longitude, which allows them to be georeferenced (“TIGER Overview”).

4.1.6. Population Demographics (“United States: Cities”)

The cities in the Appalachian coal seam region are also georeferenced and contain the same information that TIGER provides in its database, but these were obtained from the Environmental Systems Research Institute. This data is used for two purposes. The first is to determine the proximity of Tom’s Creek Impoundment to local populations and therefore to be able to assess the numbers of people that could be affected by its leakage or breakthrough. The other purpose is to use this information to georeference the location of the impoundments in the Appalachian coal seam region.

4.1.7. Water Monitoring Data (VA Division of Mined Land Reclamation)

To assess the effects on the local creek, water quality was obtained from the Virginia Division of Mined Land Reclamation. This data is georeferenced using the State Plane coordinate system, which must then be converted to longitude and latitude to be compatible with the other GIS data. The data consists of a readings taken once a month for each item tested, dating from January 1995 to March 2002.

4.1.8. LIDAR (Tuck)

For an even closer look at the impoundment itself, LIDAR data from Tuck Engineering was used for contour mapping accurate up to one foot. LIDAR is an acronym for Light Detection and Ranging and is similar to RADAR except a laser is used instead of radiowaves to send out pulses of light. Triangulating the results from multiple receivers at different locations can locate a target in three dimensions. Surface contours can be determined from using a scan mirror that directs the beams to different areas of the target and finding the small differences in distance to the target (“LIDAR Tutorial”).

4.1.9. AutoCAD

Based on digital pictures taken during a site visit of Tom’s Creek Impoundment and on a diagram provided by Coastal Coal Company, an AutoCAD model of the facility was created by scaling each of the buildings from the information in the diagram. Three dimensional solids were used for the modeling of all parts of the facility except the more complicated conveyer belt and truss. This part was created by modeling a 3D elongated box and then subtracting a smaller box to make it hollow. 3D extruded triangles were then subtracted from the sides to resemble a truss.

4.2. Methodology

To begin the visualization process, the different GIS data layers were brought into ArcView, a powerful GIS toolkit produced by the Environmental Systems Research Institute that allows the data to be georeferenced as well as facilitates having multiple data layers in one project. The

table of data on all of the impoundments from MSHA had each impoundment linked to a town, not to a latitude and longitude. It was therefore necessary to merge this file with data on the cities in the Appalachian coal seam region in order to place the impoundments on the map. Once this was accomplished the impoundments were broken down further and categorized by both breakthrough potential and by potential impact in the case of a breakthrough. The hydrology shapefile was added, and so it became possible to see which impoundments had a high break potential and were also near major waterways. DOQQs of the area around the Tom's Creek impoundment were layered on top as image analysis data sources. Bringing in the DEM of the area involved some manipulation of data (see appendix), but once this was accomplished the DOQQs were lined up with the DEM in the correct geographic alignment.

Bryce 5 software was used to create the actual 3D model of the terrain. In Bryce the DOQQ images are overlaid and stretched to fit onto the terrain created from the DEM. Because parts of the DOQQs extended past the DEM, the images had to be cropped first so that this distortion does not occur. This was accomplished using Adobe Photoshop. Photoshop was also used to create images from some of the data layers from ArcView—e.g., hydrology, cities, and location of water monitoring stations—so that they could be used in Bryce.

For an even closer look at the impoundment, a DEM was created from the LIDAR contours, accurate up to one foot. These contours are of the actual impoundment basin, and the area immediately surrounding it. In order to represent the entire facility, the buildings adjacent to the impoundment were created using AutoCAD. The model was grouped into different parts so that each could represent different materials. The trusses were divided into four groups because the amount of surfaces surpassed AutoCAD export limitations. Each group was then exported in .3ds file format. These models were imported into Bryce and used with the low and high resolution DEMs to accurately represent the terrain of the impoundment.

In Bryce, columns were placed at the location of the monitoring stations to represent the levels of manganese and iron in the waterways. The height of the columns was determined by multiplying the actual levels of the pollutants by a constant. Each keyframe represents a month in the five-year period being illustrating, with each being spaced a second apart. The water monitoring data, however, had months missing throughout the five-year period. In order to account for these missing readings, the values were interpolated using the reading taken in the previous and next months.

The final portion of the visualization was created using Macromedia Flash software. Once again the DOQQs and hydrology data from ArcView were used. A screenshot was taken of the desired map in ArcView and saved as an image file. This image was then brought into Flash and an animation was created where the rivers that could be affected by an impoundment breakage were highlighted in green.

The last step in creating the visualization is to merge each individual portion together to create one fluid animation. This is done using Edge Viewer by Autometric, and using the default world view as a starting off point for the visual.

5. Results

The final product takes the ground data on water quality in Tom's Creek and layers it on top of remote sensing data to create a three dimensional visualization which addresses the community's concern over the potential environmental hazards of the coal impoundment. The visual begins with a view of the Earth and zooms into the six-state region—Pennsylvania, Ohio, West Virginia, Virginia, Tennessee, and Kentucky—that makes up the Appalachian coal seam. The impoundments in the region are plotted on this map, and ranked according to breakthrough potential and who would be affected if the impoundment were to break ("Impoundments Search Page"). Zooming in further, the area around the impoundment is shown. Tom's Creek Impoundment is pointed out, as well as Tom's Creek, the upstream and downstream monitoring stations, the industries along the waterway, and the town of Coeburn. The visual then shifts from a 2D view to a 3D animation, with a flythrough of the actual impoundment using the LIDAR and AutoCAD data. Subsequently, the visual illustrates the level of iron and manganese at the upstream and downstream monitoring stations, represented by columns at these sites. The heights of the columns represent the level of each metal, with the amount in milligrams per liter indicated above the column. The visual then transitions back to a 2D view of the area, and zooms to a larger area. Here, the hydrology of the surrounding counties is shown, with the rivers highlighted that would potentially be affected if Tom's Creek Impoundment were to breakthrough into an underground mine. Additionally, towns along the affected waterways are represented as yellow dots and cities with populations greater than fifty thousand in the six-state region are represented as red dots.

From the visual, several key observations can be made. For the time period covered—1998 to 2002—the maximum level of iron in the water occurred on 5 January 1999, where it reached a level of 1.1 mg/L at the downstream monitoring station, and the maximum level of manganese occurred on 17 March 1998, where it also reached a level of 1.1 mg/L but at the upstream monitoring station. Additionally, the visual clearly illustrates that in general, the level of iron in Tom's Creek is higher upstream than downstream. Preliminary research and analysis of the other industries along the waterway suggests that these are not responsible for the iron or manganese in the water. Only one of the industries upstream of Tom's Creek is a source of water discharges; however, it is not releasing iron or manganese into the creek ("Enviromapper"). Therefore, this result initially suggests that there may be leakage occurring from the impoundment into Tom's Creek.

According to the EPA's National Secondary Drinking Water Regulations, the level of iron in drinking water should not exceed 0.3 mg/L ("Current Drinking Water Standards"), and the level of manganese should not exceed 0.05 mg/L. Tom's Creek, however, is not a potable water source (Wiles) so the levels of iron and manganese would not pose a threat to humans through their drinking water. Because the levels far exceed the standard set by the EPA, there is still cause for concern, especially since Tom's Creek flows through the town of Coeburn into the Guest River.

In addition to environmental pollution, the other area of concern regarding coal slurry impoundments is their potential to breakthrough into underground mines resulting in massive ecological damage and effects on human populations, similar to what occurred in Martin County,

Kentucky in October of 2000. In terms of existing legislation addressing this issue, however, little was found in the research done that deals with preventing breakthroughs. As mentioned, in Virginia, new impoundments do in fact have to meet regulations before they can be approved. Already existing impoundments pose the greatest threat on communities because of the inaccurate mapping of underground working beneath them. The last portion of the visual illustrates where downstream would be affecting if Tom's Creek Impoundment had a breakthrough. This finding was based on a comparison between the area looked at for this project and the Martin County Coal Spill. The sludge could potentially flow from the impoundment into Tom's Creek, then into the Guest River, and finally into the Clinch River down to Norris Reservoir in Kentucky. The only towns along the river are Coeburn, Dungannon (population 317), Clinchport (population 77), and Sneedville (population 1257).

6. Conclusion

The final product completed as a result of this project has far reaching implication for several different groups. The local communities will benefit from the data collected and the analysis done. While the water monitoring data is available to anyone, it is difficult to obtain without knowledge of the correct contacts and exactly what to ask for. Additionally, a list of numbers is not beneficial to those concerned with their local waterways. The three dimensional visualization created enables the local population and decision makers to better understand the effects of the impoundment on their community. While this result does not definitively identify Tom's Creek Impoundment as the source of the rise in iron levels, it will serve as the starting point for further research into the impoundment's effects on Tom's Creek. Additionally, Coastal Coal Company is interested in using a similar visualization, in real-time, to monitor their impoundment. This would allow them to detect any breakthroughs or leakages immediately and act accordingly to correct the situation. Therefore, the work done can be implemented as a Decision Support System for both the community of Coeburn and the coal company. Of course, NASA also benefits in that these remote areas are being exposed to NASA technology and the benefits that NASA can have on their communities.

Although the focus of this work is on the Tom's Creek Impoundment in Coeburn, Virginia, because it is a pilot product, it can be applied to any coal impoundment anywhere throughout the region and even the world. The only requirement is that data must be available. As was the case with West Virginia, water monitoring data was hard to come by, and therefore, the product would not have been as beneficial in informing the community of the possible dangers to their waterways. Therefore, this in an area that needs improvement. However, the technology that was used this summer is applicable to other areas as well, and as aforementioned, is an example of a Decision Support System, where data from any area can be inputted to obtain meaningful results.

7. Recommendation for Further Research

- Present final visualization and results to Wise County and Coastal Coal Corporation.
- More data sets need to be incorporated into the analysis of the environmental effects of the coal impoundment. These include, but are not limited to, the following:
 - Vegetation data along Tom's Creek
 - Wildlife health in the Coeburn area
 - Human health statistics in Wise County compared to national averages
- Adding more data sets will aid in determining if the higher level of iron downstream of the impoundment is in fact due to leakage of the impoundment.
- It must be determined with more accuracy how far downstream the coal sludge would travel if the impoundment were to break, taking into account flow rates and diffusion, for example.
- A real-time 3-d visualization should be created using the NPDES data on the sediment ponds and ground water stations of the impoundment, and this can also be presented to Coastal Coal Company.
- Another spin on this project, which there was not enough time to pursue this summer, is to use remote sensing to choose safer locations for future impoundments.

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Appendix

How To Make DEMs and DOQQs Line Up Correctly In Bryce

1. Begin by importing the DOQQs in Arc View. Open ArcView and start a new project.



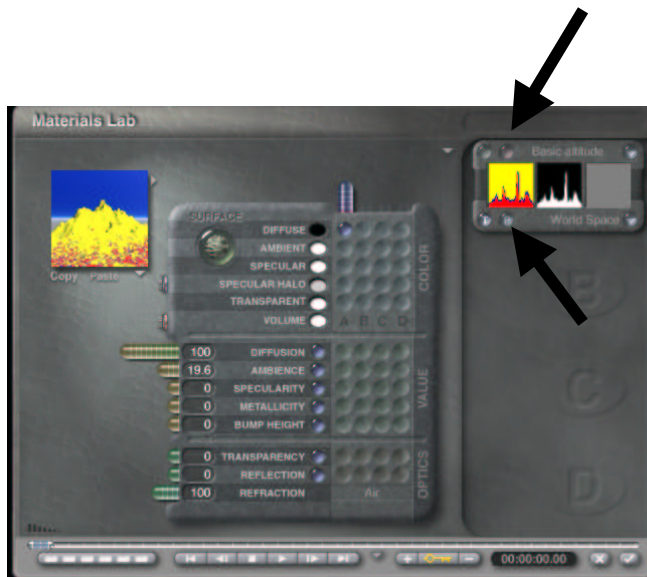
- To import the DOQQs go to the “Add a Theme” button:
2. Select all of the DOQQs (if there is more than one), and go to Image Analysis – Mosaic, this will merge all of the DOQQ’s into one picture.
 3. Go to File - Import Data Source, select DEM and press OK. Import the DEM that you downloaded.
 4. Select the DEM, as you can see the DEM is smaller than the DOQQ. You want the DEM and the DOQQ to be the same size so that they match up. So, select the Mosaic DOQQ, and go to Image Analysis – Properties. Under Analysis Cell Size, set it to “Same As Imgrd 1” and click OK.
 5. Go to Image Analysis – Subset, and leave it as it is (should be 1, 2, 3) and click OK. Now the DEM and the DOQQ should be the same size and another theme is automatically added.
 6. Select that new theme and go to Theme – Save Image As and save the image as a tiff.
 7. Open Bryce and go to File – Import Object and select the DEM that you downloaded.
 8. Now you should be able to see the DEM in Wire Frame Mode. Look to the right and you should see a drop down box that looks like this:



Hit the M, this is the Materials Lab.

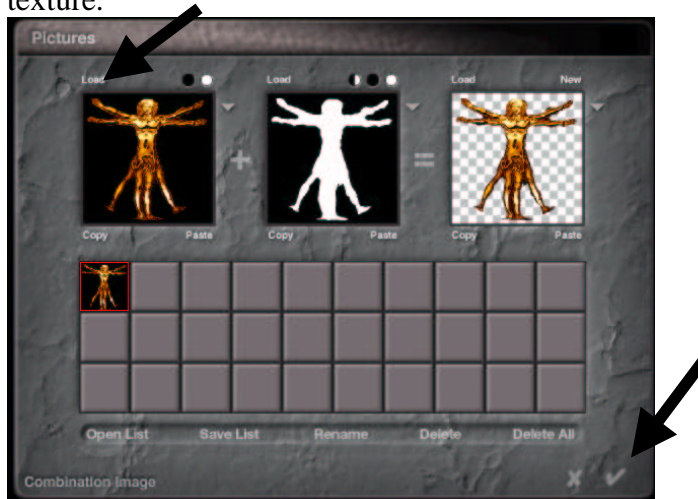


9. Click on the oval area right next to the Diffuse button. This will bring up the Textures.



10.

Now click on the P button at the bottom then select the button directly above red colored button. This brings up the picture loader so you can load the picture as a texture.



11.

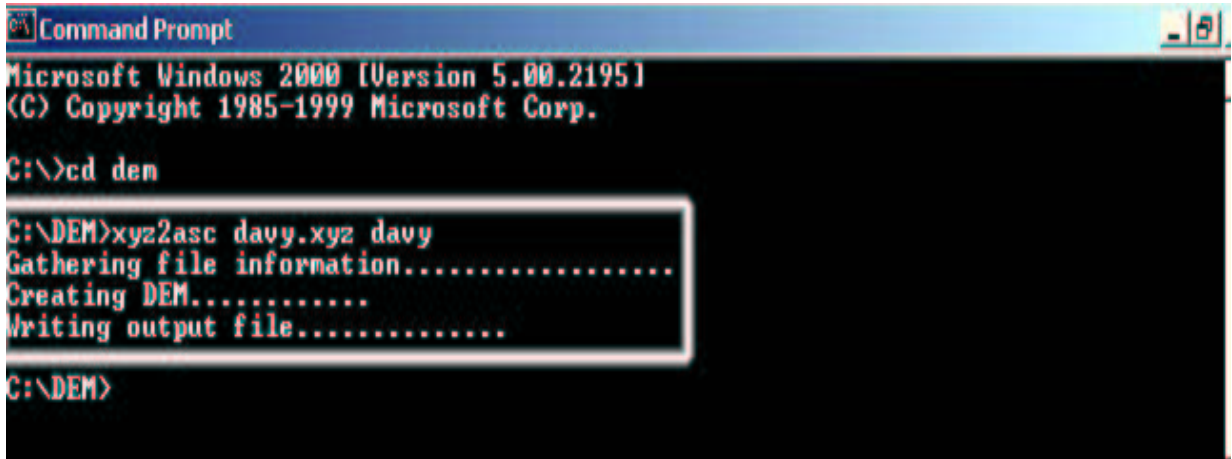
Click on the load button and load the tiff that you saved in ArcView. Hit the check mark on the bottom of the screen and do the same on the other screen.

Importing SDTS DEMs into ArcView

ArcView 3.2 does not support the SDTS DEMs so you have to reformat the DEMS. Make sure that you have MicroDEM on your computer, but if you don't go to <http://www.usna.edu/Users/oceano/pguth/website/microdemdown.htm> and download it, as well as the xyz2asc program that Aaron Dalton wrote.

1. First go to the C drive and right click. Go to New – Folder, and name the folder DEM.
2. Open MicroDEM and go to File – Open DEM. Go to the folder that has the SDTS DEM, and select the CATD.DDF file.
3. Go to Save DEM – ASCII, rename the DEM and save it in the folder that you created in the C drive. Save it as an integer.
4. Go to Start – Accessories – Command Prompt.

5. Type “cd dem.” (The command “cd” changes the active directory.)
6. Now you should be in the DEM folder. Type “xyz2asc name.xyz name,” replacing *name* with the name of the DEM.



```
Command Prompt
Microsoft Windows 2000 [Version 5.00.2195]
(C) Copyright 1985-1999 Microsoft Corp.

C:\>cd dem

C:\DEM>xyz2asc davy.xyz davy
Gathering file information.....
Creating DEM.....
Writing output file.....

C:\DEM>
```

The information that you type should look like the highlighted area.

Now the DEM is an ASCII file which can be imported into ArcView. Follow steps 3 – 11, but in step 3 instead of DEM, go to ASCII Raster. You can import the SDTS DEMs directly into Bryce without having to format it.